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DESIGN, FABRICATION AND CALIBRATION OF SIX IRIDIUM VERSUS IRIDIUM - 60 RHODIUM THERMOCOUPLES

FINAL REPORT ON TASK ORDER 11

to

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama

Southern Research Institute
Birmingham, Alabama
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SUMMARY

Six iridium versus iridium-60 rhodium thermocouple assemblies were designed, fabricated, and calibrated. The thermoelectric output of the wire was determined, and the effect of thermal cycling on emf stability was evaluated. After the first exposure, the emf-temperature characteristic was fairly reproducible. The thermocouples performed well in repeated exposures to an oxy-acetylene flame. The major disadvantage of this thermocouple was embrittlement of the wires after high temperature exposures.

PERFORMANCE GOALS

The thermocouples were designed to the following goals:

1. Sheath and housing to withstand exposure to 2000°C (3600°F) maximum temperature for a period of up to 20 seconds.

2. Assembly to withstand vibration levels up to 48g maximum acceleration at frequencies ranging from 140 cycles/sec to 2000 cycles/sec.

3. Assembly to be 100% waterproof.

4. Assemblies to be designed, constructed, calibrated, and delivered to NASA within nine weeks after initiation of the Task Order.

5. Configuration to conform to MSFC drawing 50M10100.

DESIGN AND CONSTRUCTION

The design was basically of the configuration shown in MSFC drawing 50M10100, modified as necessary to meet the performance requirements. The final assembly is shown in drawing 1481-11-D-1 attached and in the schematic portion from that drawing reproduced as Figure 1. The high temperature structural components were made of molybdenum. To provide sufficient resistance to vibration damage, all major components were joined with both welded and mechanical joints. Welds were made in a dry box using the tungsten inert gas process.

The thermocouple assembly (part No. 1A in drawing 1481-11-D-1) consisted of a molybdenum sheath, 0.125 inch O. D. x 0.094 inch I. D., joined to a 0.250 inch O. D. molybdenum support tube. The joint was made at the rear (unexposed) end of the assembly by flaring the sheath to match a chamfer in the support tube, and tack welding in two places. The sheath was originally specified to be of swaged molybdenum tubing using high purity thoria for electrical insulation; however, due to the extreme brittleness of the molybdenum, attempts to form a swaged sheath were unsuccessful. After several attempts to swage the tubing at low temperatures (200°F-300°F) it was realized that the operation would have to be performed at temperatures near 1000°F in order to obtain a sufficient reduction in the tube diameter without splitting it. The time and cost involved to design the necessary fixtures precluded this method, and as an alternative outside sources were sought to perform the operation. Hayes Aircraft Corporation attempted to swage the sheaths, but lacking experience in working molybdenum, were also unsuccessful. The Cleveland Tungsten Corporation, Cleveland, Ohio, a manufacturer of molybdenum tubing, was engaged to make the swaged sheaths, but their attempts were also unsuccessful. The General Electric Company, West Lynn, Massachusetts, was also contacted and expressed confidence in their ability to fabricate the assemblies; however, they were unable to meet the required delivery schedule.

Failure of the swaging operations led to investigations of other solutions and finally, a technique was developed to pack magnesia powder in the molybdenum sheath. This was done at temperature of 600°F, in order to take advantage of thermal expansion of the sheath to obtain a higher insulation density. To contain the powder, the exposed end of the sheath was heated to a dull red color and peened slightly. Both ends of the sheath were plugged with a short length of fired magnesia double bore tubing. A short length of each thermocouple wire was flattened slightly to prevent rotation within the sheath. The selection of the magnesia powder insulation involved considerable evaluation, as discussed later.

The insulation was packed in the sheath using a special fixture after acid pickling the sheath to remove scale and impurities. Care was taken to prevent dirt from entering the sheath during the packing operation.

Other features of the design are described briefly in the following paragraphs. Part numbers refer to the components in drawing 1481-11-D-1.

The insulation used in the support tube (part 102B) proceeding from the sheath was a double bore magnesia tube which extended to the rear end of the support tube and was surrounded by a packed magnesia powder to hold it in place. The wire inside the flexible stainless steel conduit (108) proceeding away from the support tube was insulated with individual strands of teflon inner sleeving. Calculations indicated that the temperature at the junction between the teflon and magnesia would approach 2000°F within approximately 60 seconds after the sheath, body block (107), thermocouple assembly (1-A) and protection tube were exposed to 3600°F at a heat flux density of 100 Btu/ft^2/sec. Therefore, an outer jacket of Refrasil sleeving was used for high temperature insulation in this area of the junction between the support tube and the conduit. Refrasil has a maximum service temperature of approximately 2000°F. Where the wires emerged from the open end of the conduit, a plastic coated Refrasil was used over the teflon for protection from abrasion. For strain relief, the wires were potted in the open end of the conduit with epoxy cement and at the junction of the conduit and the thermocouple block with a silastic cement.

The junction between the molybdenum support tube (102B) and the stainless steel conduit (108) posed some problem. It was thought that a mechanical connection would loosen under the extreme vibration encountered in flight, and the 2000°F temperature precluded a silver soldered joint. After some experimentation, a brazing technique was perfected, using copper as the braze metal.

The $\frac{1}{4}$ inch bore through which the annulus between the support tube and the double bore magnesia tubing was packed was sealed with zirconia cement. This procedure provided protection against the loss of the magnesia powder through the rear of the sheath and out of the support tube by vibration.

For moisture protection, all exposed areas were covered with a silastic compound, RTV-31, which vaporized when heated, without leaving an electrically conducting residue.

An additional item of equipment not shown in drawing 1481-11-D-1 was the zone box used to correct for a variable cold junction temperature. These were purchased to NASA specifications from the RDF Corporation, Hudson, New Hampshire. The operating principles are described in detail in a NASA internal publication. Basically the zone box consists of a precision platinum resistance element which forms one leg of a bridge circuit. The resistance versus temperature characteristic of the platinum leg is such that an opposing emf is generated which cancels out the emf of the thermocouple cold junction, thus providing a constant reference junction temperature.

DEVELOPMENT AND QUALIFICATION TESTING

Selection of Electrical Insulation

Selection of a suitable electrical insulation for the thermocouple sheath involved considerable effort. The original NASA specifications called for high purity thoria; however, a survey of possible suppliers revealed that none could supply thoria in higher purities than 99.5% from stock, with 99.8% purity being avaliable on six weeks delivery.

From previous work here, it was suspected that even slight amounts of impurities, particularly silica, in the thoria would result in breakdown of electrical resistance at about 3000°F. We believed that for adequate electrical resistance, purities of $99.9^{+}\%$ would be required. Such high purity thoria was not readily available. Regardless of the mechanism, we knew that the resistivities of thoria, magnesia, and beryllia were roughly comparable at the high temperatures required for this probe.

Magnesia (MgO) and beryllia (BeO) were next evaluated as suitable substitutes. The electrical resistance of each was measured in several tests using the apparatus shown in Figure 2. The magnesia insulated sheath consisted of MgO powder backed in 0.125 inch O. D. x 0.094 inch I. D. molybdenum tube. For comparison the resistance of a double bore magnesia insulator was measured. The double bore insulators were wrapped with molybdenum wire to simulate the sheath. An iridium/iridium-60 rhodium thermocouple was installed in each sheath, thus permitting simultaneous measurements of both electrical resistance and thermoelectric voltage over the temperature range from 70°F to 3600°F. Electrical resistance was measured using a standard ohmmeter. Thermoelectric voltage was measured with a Leeds and Northrup potentiometer.

The electrical resistance of an assembly packed with USP standard grade magnesia powder insulation is shown in Figure 3. Note that the resistance dropped sharply with increasing temperature, decreasing to only 40 ohms at 3230°F. The resistance increased considerably between the second and third runs, possibly due to vaporization of silica and other impurities at about 2000°F.

The sharp drop in resistance at the higher temperatures caused some concern. However, a review of the literature revealed that similar results had been obtained by others. Blackburn and Caldwell[1], who compiled the National Bureau of Standards reference tables for iridium/iridium-60 rhodium thermocouples reported considerably lowered resistance of both thoria and beryllia insulators at higher temperatures. They believed the thoria to be the poorer insulator and replaced it with beryllia. With the beryllia insulators, the resistance between wires "decreased to a few tens of ohms at 3800°F."[1]

Lachman and McGurty[2] evaluated thoria insulators and reported that, due to the presence of iron in the thoria, it offered no improvement over beryllia.

Based on our own experience and the results reported in the literature, it was decided to eliminate thoria as a possible insulator, and to direct subsequent efforts toward the selection of either magnesia or beryllia. Several measurements of electrical resistance versus temperature were made using double bore insulators of both materials. These insulators were wrapped with numerous turns of 0.007 inch diameter molybdenum wire to simulate the sheath, and resistance was measured between both thermocouple wires and between one thermocouple wire and the molybdenum wire. The results are plotted in Figure 4. Note that the values are comparable, the resistance of beryllia being about 70 ohms at 3600°F compared to about 50 ohms for magnesia. The slightly higher values for beryllia probably were due to its larger diameter.

The thermoelectric outputs of the iridium/iridium-60 rhodium thermocouple using the various insulators are shown in Figures 5 and 6. Note that the insulator had no apparent effect on the thermocouple output, and that above 2500°F the values exhibited excellent agreement with the reference values reported for bare wire by Blackburn and Caldwell[1]. As shown in a following section, the tendency of the data to fall below the reference curve at the lower temperatures was due to conduction of heat from the junction. As will be shown, when the couple was exposed to a sufficiently high heat flux density or when the length of the isothermal zone was increased, the experimental values fell on the reference curve.

The effect of thermal cycling after the initial cycles was quite small, as shown in Figures 5 and 6. The maximum difference between the first and fourth runs was about 8% at 1500°F for the magnesia insulated thermocouples. About the same difference was exhibited between the first and second runs on the beryllia insulated thermocouple.

From the results of the evaluations just described, it was concluded that magnesia would be a suitable electrical insulator. However, the powder form employed had exhibited considerable shrinkage after exposure to elevated temperatures. Several powder compositions were subsequently evaluated to find one which exhibited sufficient dimensional stability. Several molybdenum sheaths were packed with reagent grade magnesia, which contained fewer impurities than the USP standard grade used previously. These were inserted in the blackbody cavity, which was heated to 3600°F, held for approximately 30 seconds (to simulate the time duration in flight) and withdrawn. The reagent grade magnesia exhibited less shrinkage than the USP standard grade, but was not considered satisfactory.

Since it was believed that impurities and sintering caused the shrinkage, several mixtures of powder were made using different percentages of reagent grade powder plus larger granules of arc cast magnesia, ground and sifted to pass 40, 60, or 100 mesh screens. After several trials, it was found that a mixture of 25% reagent grade magnesia with 75% arc cast magnesia (100 mesh) exhibited no observable sintering and that the mixture remained firm in the sheath after exposure to 3600°F. This mixture was subsequently used in the final assemblies using a special fixture to pack it in the sheath at a temperature of about 600°F.

Vibration Tests

To establish the ability of the thermocouple to withstand flight-level vibrations, two prototype thermocouples (designated Nos. 1 and 2) were fabricated and exposed to several vibration tests. The most severe exposures were at a double amplitude of 0.125 inch and 60 cycles/second, resulting in a maximum acceleration of 22 g's, which was the maximum output of the vibrator equipment.

Thermocouple No. 1 was subjected to four vibration tests in the orientations shown in Table 1. The only visible damage occurred in test No. 4 in which the orientation simulated the flight mounting conditions with the sheath pointed vertically downward. Some insulation was shaken out of the sheath, but the bead and thermocouple wires remained intact and continued to function. For this thermocouple assembly the short length of solid, double bore protection tube had not been inserted in the end of the sheath to help hold the powder in place.

Thermocouple No. 2 was tested with the sheath pointed vertically downward as shown in Table 1. A few pieces of the solid insulation were shaken from the sheath, and the weld joining the support tube and the body block (parts 102B and 107) cracked. This damage was concluded as tolerable since we initiated closer inspection of the short length of double bore tubing to ensure that it was not cracked during packing of the sheath, and since the block to support tube weld was designed to perform mechanically even with cracking of the weld. Further, the emf versus temperature characteristic of the thermocouple was unchanged. During subsequent measurements of response time, this thermocouple performed satisfactorily after approximately 25 exposures in an oxy-acetylene flame for periods of approximately 10 seconds each.

Investigation of Wire Embrittlement

It was found that after welding the bead both thermocouple wires were embrittled in the vicinity of the junction. Embrittlement also occurred to a lesser extent after cold working. Embrittlement occurred in both the wires, but was more severe in the iridium. Since this resulted in a rather fragile bead, investigations were made to determine the cause and cure of the embrittlement. Blackburn and Caldwell[1] described an annealing process which they used prior to welding in which the wires were heated electrically in air for about one minute at about 200°C below their melting points. The observed temperatures as measured with an optical pyrometer, were 3460°F for the iridium and 3180°F for the alloy wire.

Several thermocouples were made from annealed wires using this procedure but were still brittle after the junction was made.

Figures 7 and 8 show photomicrographs of the wires before and after welding, and of the thermocouple bead. Note the extremely large grain growth in both wires. The bead shows areas of both large and small grain structure.

Investigations of the embrittlement by our metallurgists failed to yield any clue as to its cause. No reference to embrittlement in iridium/iridium-rhodium alloys was found in the literature. Unfortunately, investigations had to be suspended due to lack of time and funds.

It seems possible that a suitable annealing procedure could be found which, if employed after welding, would reduce the embrittlement. Since annealing might also cause a change in the alloy compositions due to diffusion, its effect on the thermoelectric properties of the couple would require careful evaluation.

Since the thermocouple wires could not be made more ductile, the design of the assembly was modified to keep mechanical loads off of the welded bead. This was done by twisting the wires at the bead, by flattening them so they could not rotate in the sheath and in the support tube, and by restraining the lead wires in the rear end of the support tube with a silastic cement.

CALIBRATION

Calibration of Prototype Assemblies

The calibration of the wire was accomplished simultaneously with measurements of electrical insulation, as previously described. The emf output was found to be repeatable during several thermal cycling operations.

Six prototype thermocouple assemblies were constructed and calibrated, four assemblies being calibrated to 1800°F and the other two to 3600°F. The calibrations to 3600°F were performed in both the tungsten blackbody cavity previously described, and in an oxy-acetylene torch. Thermocouple No. 1 was first calibrated in the $\frac{3}{8}$ inch diameter tungsten blackbody cavity at an immersion depth of $\frac{3}{4}$ inch. Results are shown in Figure 9. At temperatures below 1800°F, the emf output fell significantly below the NBS calibration curve for the wire, due to the thermal drain induced by the relatively large mass of the unheated molybdenum housing. This effect of thermal drain from the junction was verified by suspending the entire assembly in the hot zone of a 5000°F furnace which employs a cylindrical graphite heating element with an inside diameter of $1\frac{3}{4}$ inches and a heated section $4\frac{1}{2}$ inches long. Observe in Figure 9 that the emf output duplicated the NBS data at temperatures between 1500°F and 2000°F indicating that if a sufficient portion of the assembly were at a uniform temperature, the thermocouple would indicate the true temperature.

Since for installation in the Saturn vehicle the exposure area was fixed, it was necessary to determine the emf output under simulated flight conditions. The thermocouple would be mounted in the Saturn vehicle with the body block (107), junction assembly (1-B) and protection tube (105) exposed to high temperature rocket exhaust products. Based on NASA flight measurements, it was assumed that the exposed parts would be subjected to heat flux densities on the order of 100 Btu/ft^2/sec. These conditions were simulated by mounting the thermocouple in an oxy-acetylene flame. Stagnation heat flux densities were measured using copper slug calorimeters. The temperature of the thermocouple bead was determined by enclosing the sheath with a graphite cylinder to obtain blackbody conditions and measuring the temperature of the bead with an optical pyrometer. Results are plotted in Figure 10. Over most of the temperature range the data fell on the reference curve of Blackburn and Caldwell. At about 1700°F, the output fell slightly below the curve, due to the relatively large thermal drain and low heat flux density resulting from the shielding effect of the graphite cylinder.

The previous measurements indicated that if the impinging heat flux density on the thermocouple bead were sufficiently high, errors due to thermal drain would be negligible, and the thermocouple would indicate the true temperature of the stream. To determine the heat flux density which would result in a true reading, comparative measurements were obtained on the prototype thermocouple No. 2 and a bare couple made from two uninsulated wires. The impinging heat flux density was varied by locating the couples at different distances from the burner nozzle. The prototype couple was evaluated both with and without the protection tube (105). The graphite cylinder was not used in these measurements, the beads being exposed directly to the flame. The reference thermocouple was made from uninsulated iridium and iridium-60 rhodium wires, since this configuration was subject to the minimum error due to conduction of heat from the bead. Results, plotted in Figure 11, show that the emf output of the prototype thermocouple was below that of the bare wire with the curves intersecting at a heat flux density of approximately 103 Btu/ft^2/sec. Above this heat flux density, the protection tube had no effect on the emf output. From these evaluations it was concluded that for in-flight conditions the thermocouple emf output would follow the reference curve determined for the bare wire.

The calibration of all six thermocouples is shown in Figure 12. The calibration curves for thermocouples through 5 were identical The curve for No. 6 was higher over the temperature range covered by the calibrations, but if extropolated to higher temperatures, would probably fair in with the curve for thermocouples 1 through 5.

From the previous calibrations and studies of the effect of heat flux density on thermocouple output, it was concluded that the output of the prototype thermocouples under in-flight conditions would follow the reference curve of Blackburn and Caldwell for the bare wire. The latter values are tabulated in Table 2.

Calibration of Iridium and Iridium-60 Rhodium versus Copper

To provide data for design of precision resistance elements for use in the bridge circuits employed with the zone boxes, each thermocouple wire was calibrated against copper over the temperature range from 0°C to 200°C. The apparatus used for these calibrations is shown schematically in Figure 13. The thermocouples were heated in a furnace consisting of an alumina heater core wound with Kanthal wire. A copper cylinder was inserted in the heater core to maintain an isothermal zone approximately 7 inches long. The thermocouples, insulated with double bore alumina tubes, were inserted into the hot zone through teflon bushings at each end. All thermocouple circuits were provided with 32°F reference junctions. Readings were taken on a Leeds and Northrup Type K-3 potentiometer.

Because of its high thermoelectric power, a copper-constantan thermocouple was used as a standard. The output was checked at the ice and steam points.

The results are shown in Figure 14 and Table 3. The output of the iridium versus copper junctions agreed quite closely with the data of Blackburn and Caldwell, while that of the iridium-60 rhodium versus copper differed by approximately six percent over most of the temperature range. Note that these data also can be used for calibration purposes, since for this combination of thermocouple alloys the numerical sum of the outputs of both alloys against copper at any given temperature represents the output of iridium versus iridium-60 rhodium at that temperature.

Measurements of Response Time

The time response of the thermocouple bead was determined by exposing it to an oxy-acetylene flame and measuring the time required for the thermocouple to reach 63.2 percent of its maximum or steady state output. Because of its essentially instantaneous response, an oscilloscope was selected for recording the time-temperature curves. The thermoelectric output was connected to a signal generator, so that it was displayed on the oscilloscope as a series of pulses at one-half second intervals. To determine whether the response time was affected by the sheath and housing assembly, measurements were made on both a prototype thermocouple (TC No. 2) and a thermocouple consisting of bare wires. Both thermocouples had a single twist behind the bead, with the bead on the uninsulated pair being slightly larger. Measurements on the prototype thermocouple were made both with and without the protection tube (part No. 105). The thermocouples were located at various distances from the burner nozzle in order to obtain various stagnation heat flux densities. Typical response curves are shown in Figures 15 and 16. Note that at the same heat flux density, the uninsulated thermocouple (bare wire) exhibited a slightly higher output but about the same response time as the prototype couple. The complete data, presented in Table 4, show that the response time is dependent primarily on the heat flux density impinging on the thermocouple bead, as expected. The data shown are about the same as values reported by Shepard and Warshawsky[3] for 0.020 inch diameter chromel-alumel thermocouples in air at low Mach numbers.

CONCLUSIONS

Iridium vs iridium-60 rhodium thermocouples with magnesia insulation can provide reliable temperature measurements at temperatures up to about 3800°F. Results of numerous exposures in an oxy-acetylene flame indicate that the thermocouple wires and molybdenum components will perform well in rocket exhaust environments. Embrittlement of the thermocouple wires after welding poses a problem, but it is believed that this disadvantage can be tolerated if suitable fabricating methods are employed.

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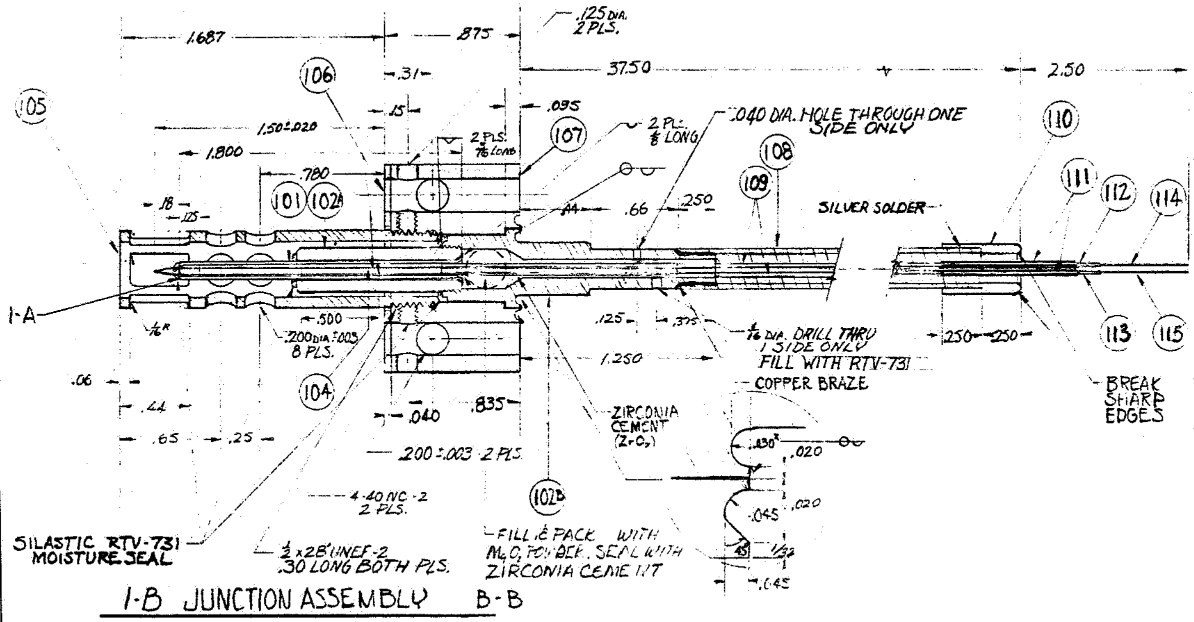
2. Lackman, J. C., and J. A. McGurty, "II. The Use of Refractory Metals for Ultra High-Temperature Thermocouples," Temperature: Its Measurement and Control in Science and Industry," Vol. 3, Part 2, Reinhold Publishing Corporation, New York, 1962, p. 186.

3. Shepard, C. E. and I. Warshawsky, "Electrical Techniques for Time Lag Compensation of Thermocouples Used in Jet Engine Gas Temperature Measurements" ISA Proceedings (1952) p. 150.



ASSY.	ITEM	QUAN.	NAME DESCRIPTION MATERIAL
1-A		1	THERMOCOUPLE ASSEMBLY
	—	1	1-B JUNCTION ASSEMBLY
1-B		1	JUNCTION ASSEMBLY
	101	1	SHEATH - .125 O.D. MOLYBDENUM .094 I.D.
	102A	1	SUPPORT TUBE - .250 O.D. .125 I.D. MOLY.
	102B		SUPPORT TUBE - MOLYBDENUM
	103	1	.094 O.D. x .022 I.D. DOUBLE BORE x 2.00 SWAGEABLE MAGNESIA THERMOCOUPLE INSULATOR
	104		MAGNESIA OXIDE POWDER 25% REAGENT GRADE 75% -100 MESH ARC CAST MAGNESIA
	105	1	PROTECTION TUBE .50 O.D. x .375 I.D. x 2.00 MOLYBDENUM
	106	1	.040 TZM PLATE WELDED TO '107'
	107	1	BODY BLOCK .835 x .620 x 1.350 MOLY
	108	1	3/16 I.D. — FLEXIBLE STAINLESS STEEL TUBING.
	109	1	REFRASIL FIBERGLASS SLEEVING SERIES 'B' 18' S395 1EK
	110		5/16 O.D. 3/16 I.D. 304 STAINLESS STEEL TUBE
	111		COATED REFRASIL SLEEVING
	112		TEFLON SHEATHING, RED
	113		TEFLON SHEATHING, GREEN
	114		IRIDIUM THERMOCOUPLE WIRE (RED)
	115		IRIDIUM-60 RHODIUM THERMOCOUPLE WIRE (GREEN)
	116	2	18 GAUGE STAINLESS STEEL HYPODERMIC TUBING 1/4" LONG

Figure 1. Iridium/Iridium-60 Rhodium Thermocouple Assembly (from Drawing 1481-11-D-1)

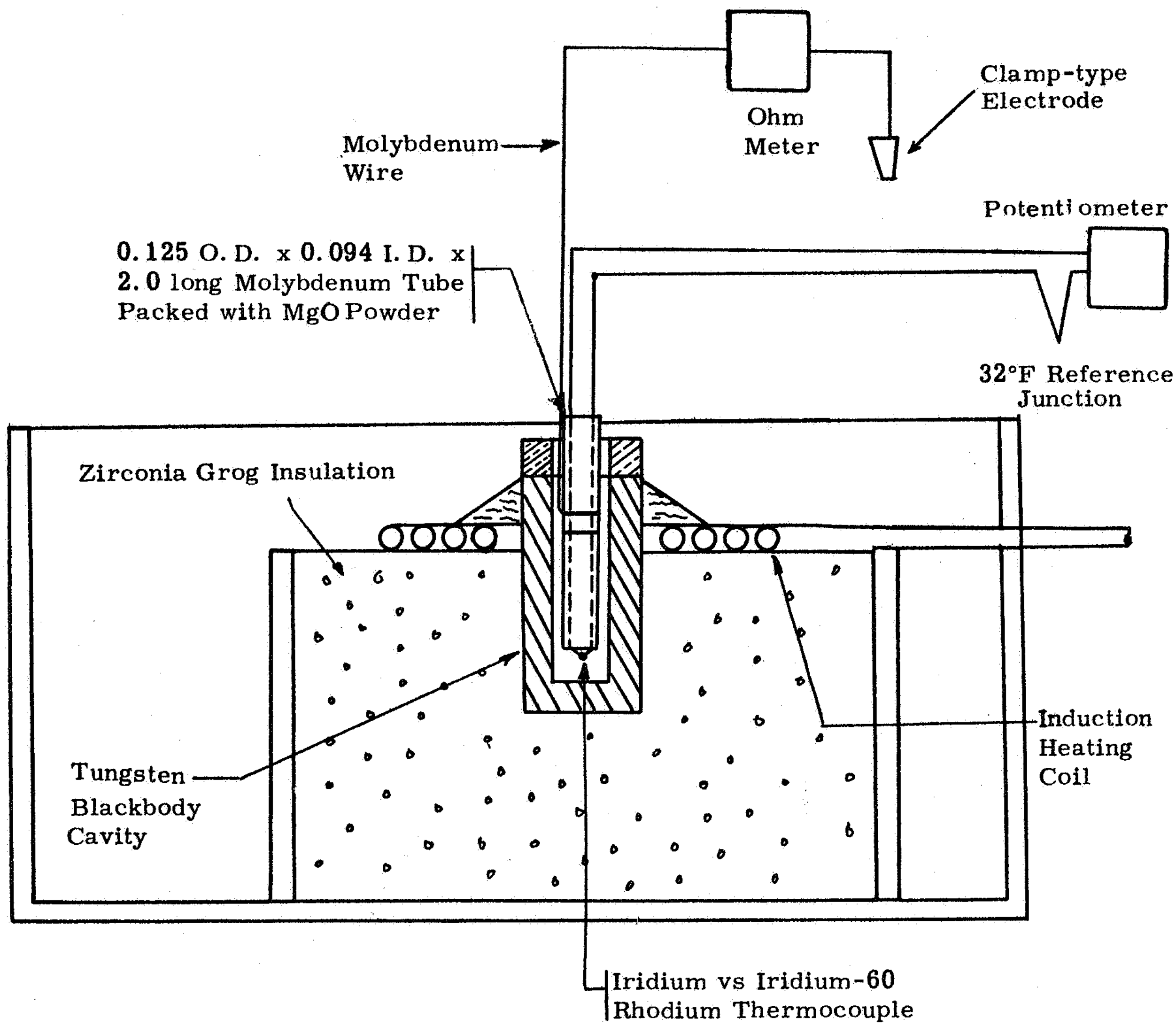


Figure 2. Apparatus Used for Measurement of Thermoelectric Output and Electrical Resistance

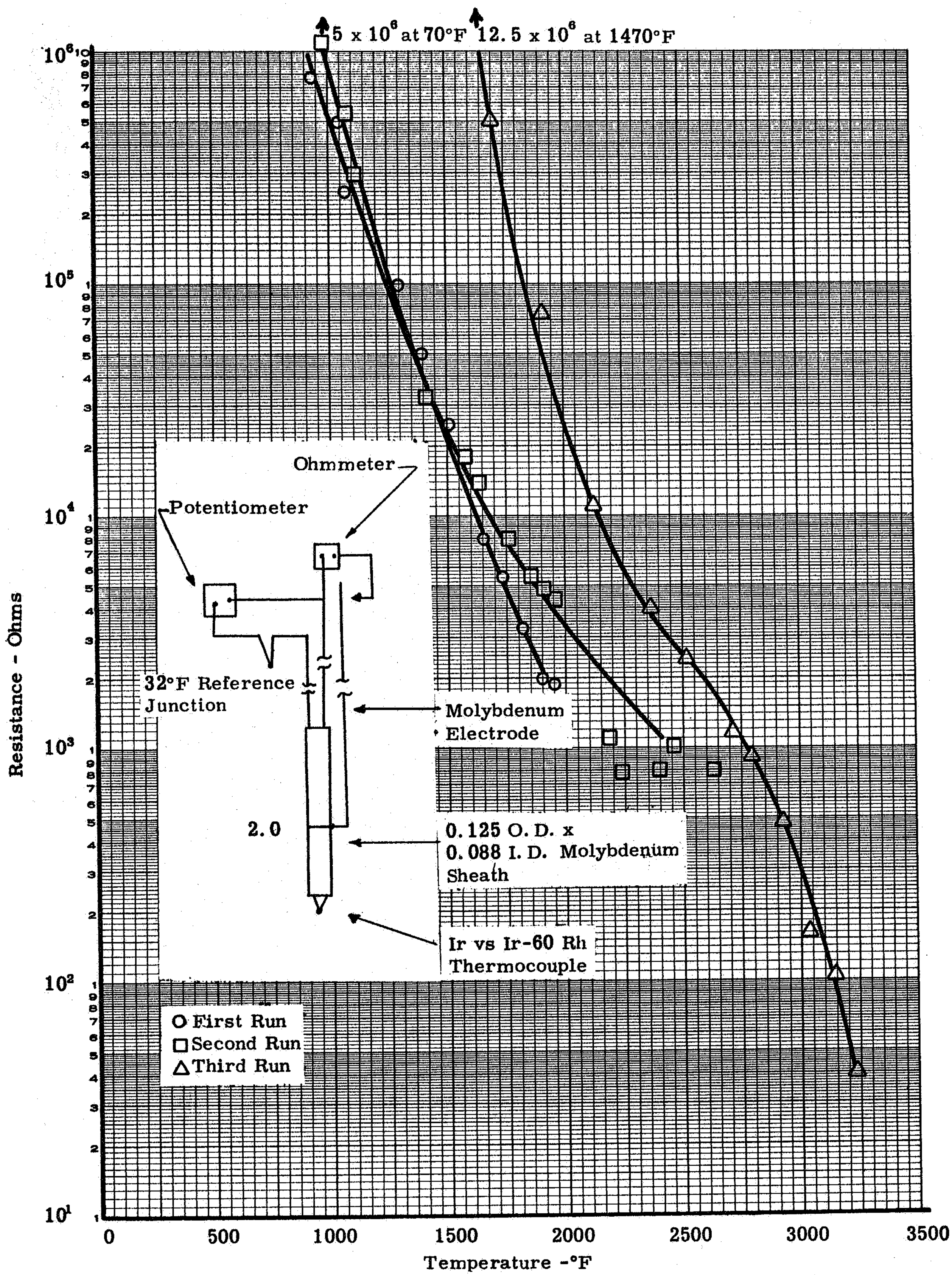


Figure 3. Resistance Between Wire and Sheath for Thermocouple Insulated with USP Standard Grade Magnesia Powder

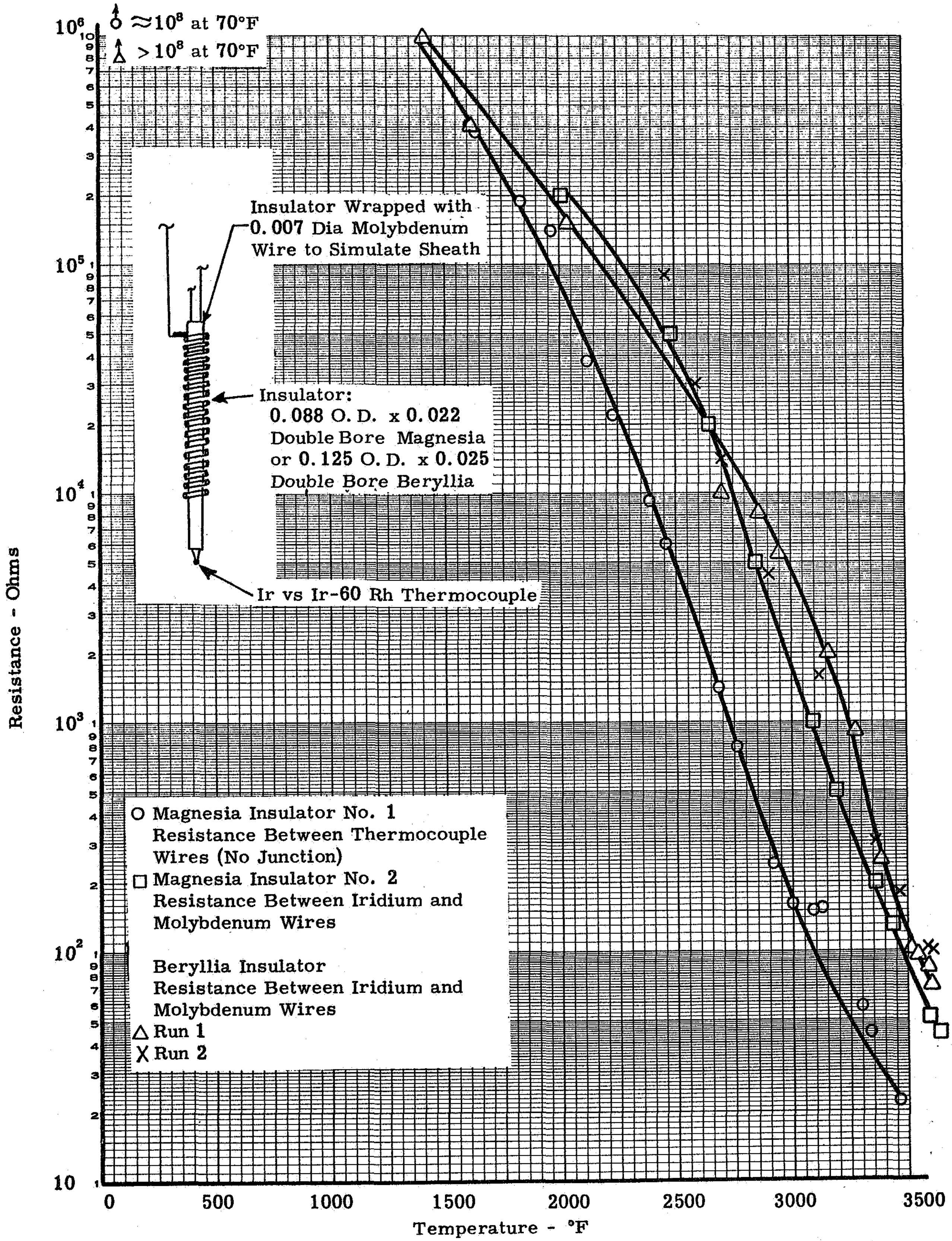


Figure 4. Resistance of Magnesia and Beryllia Insulators

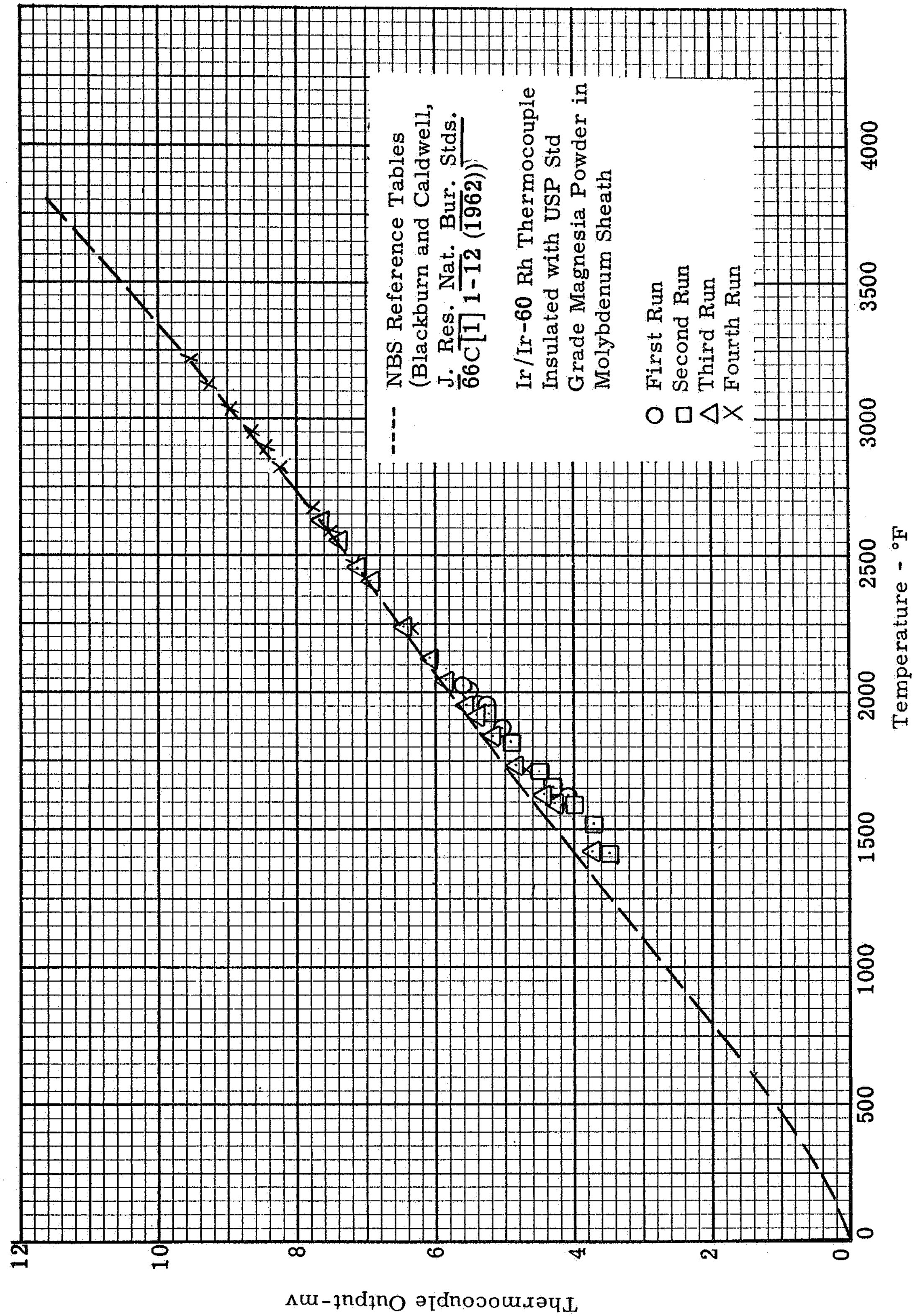


Figure 5. Thermoelectric Output of the Magnesia Insulated Ir/Ir-60 Rh Thermocouple

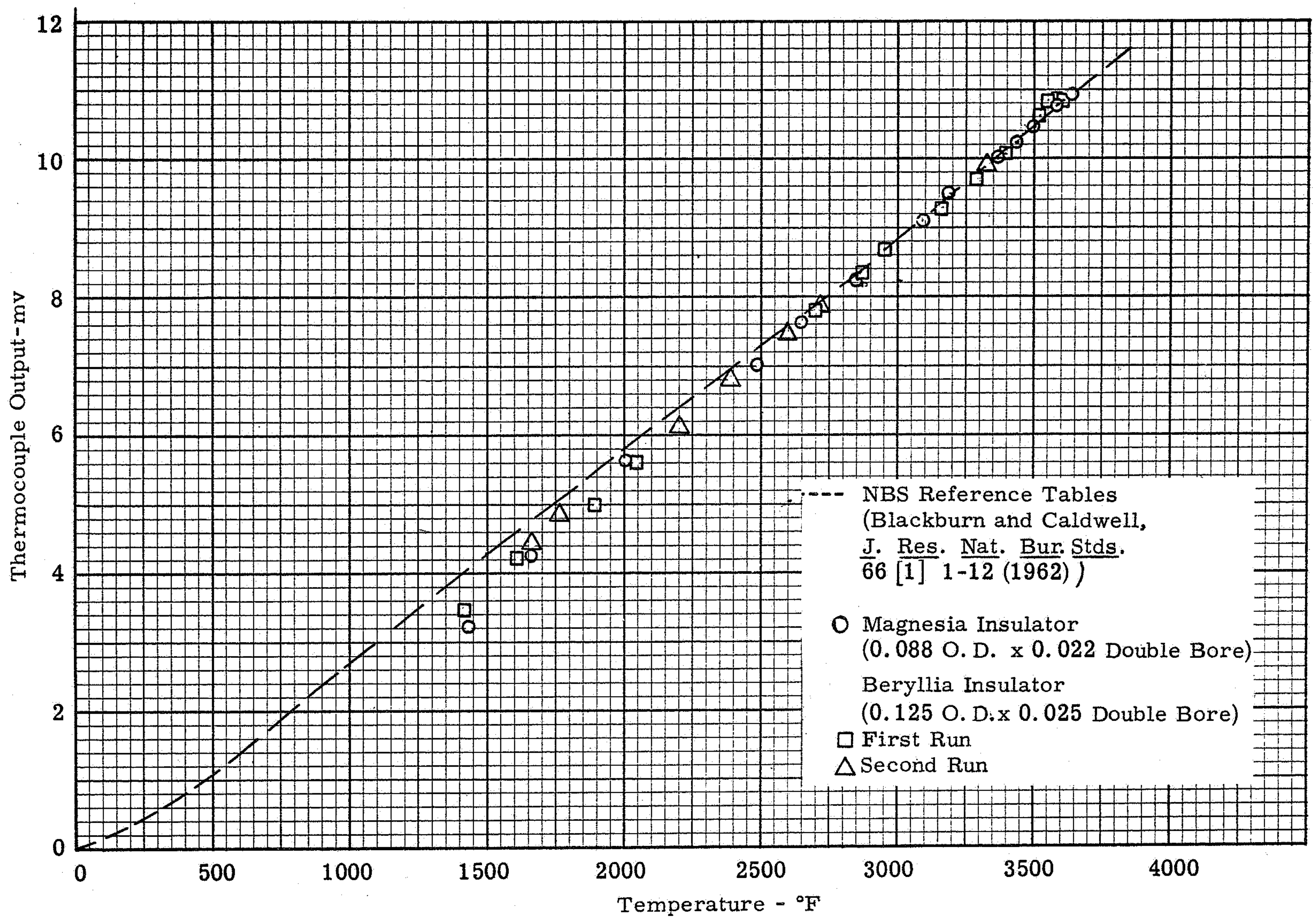


Figure 6. Thermoelectric Output of Iridium versus Iridium-60 Rhodium Thermocouples in Magnesia and Beryllia Insulators

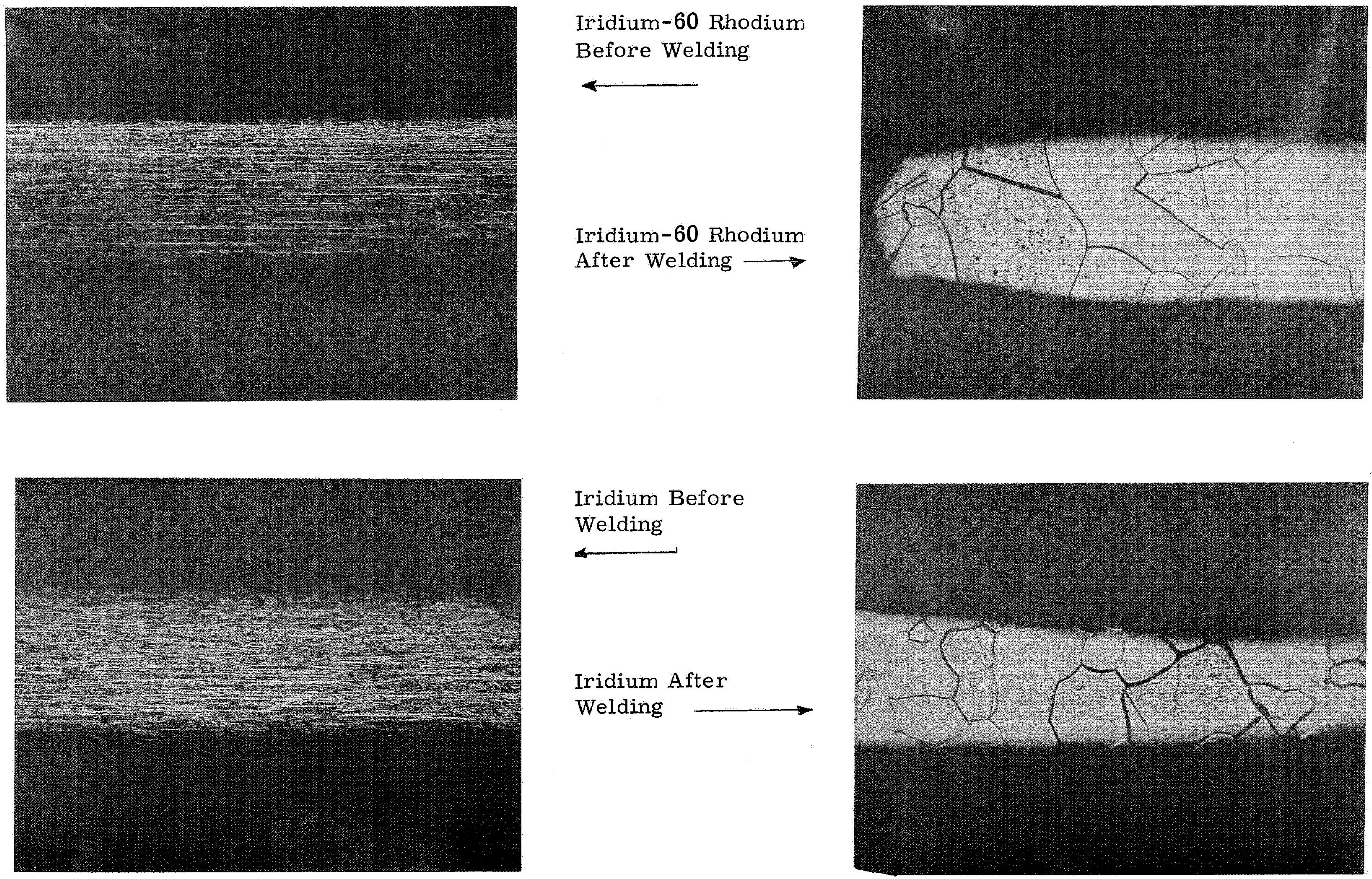


Figure 7. Photomicrographs at 75X of Iridium and Iridium-60 Rhodium Thermocouple Wires Before and After Welding

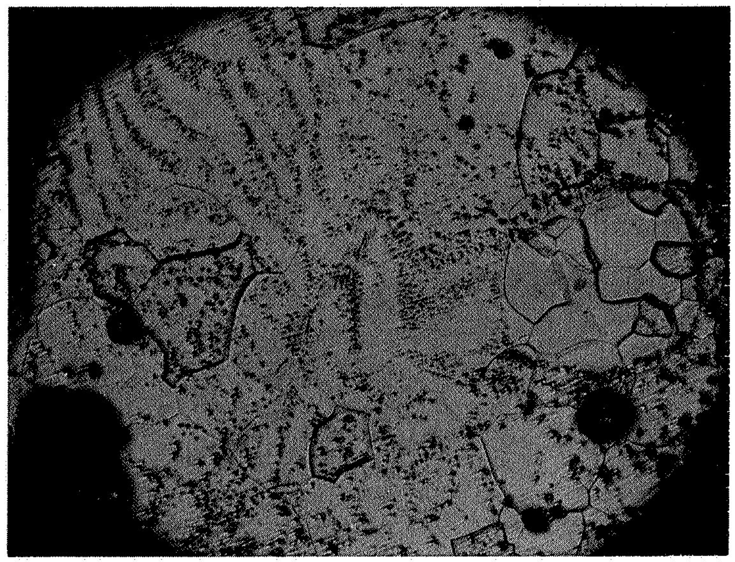


Figure 8. Photomicrograph at 75X of Iridium/Iridium-60 Rhodium Thermocouple Bead

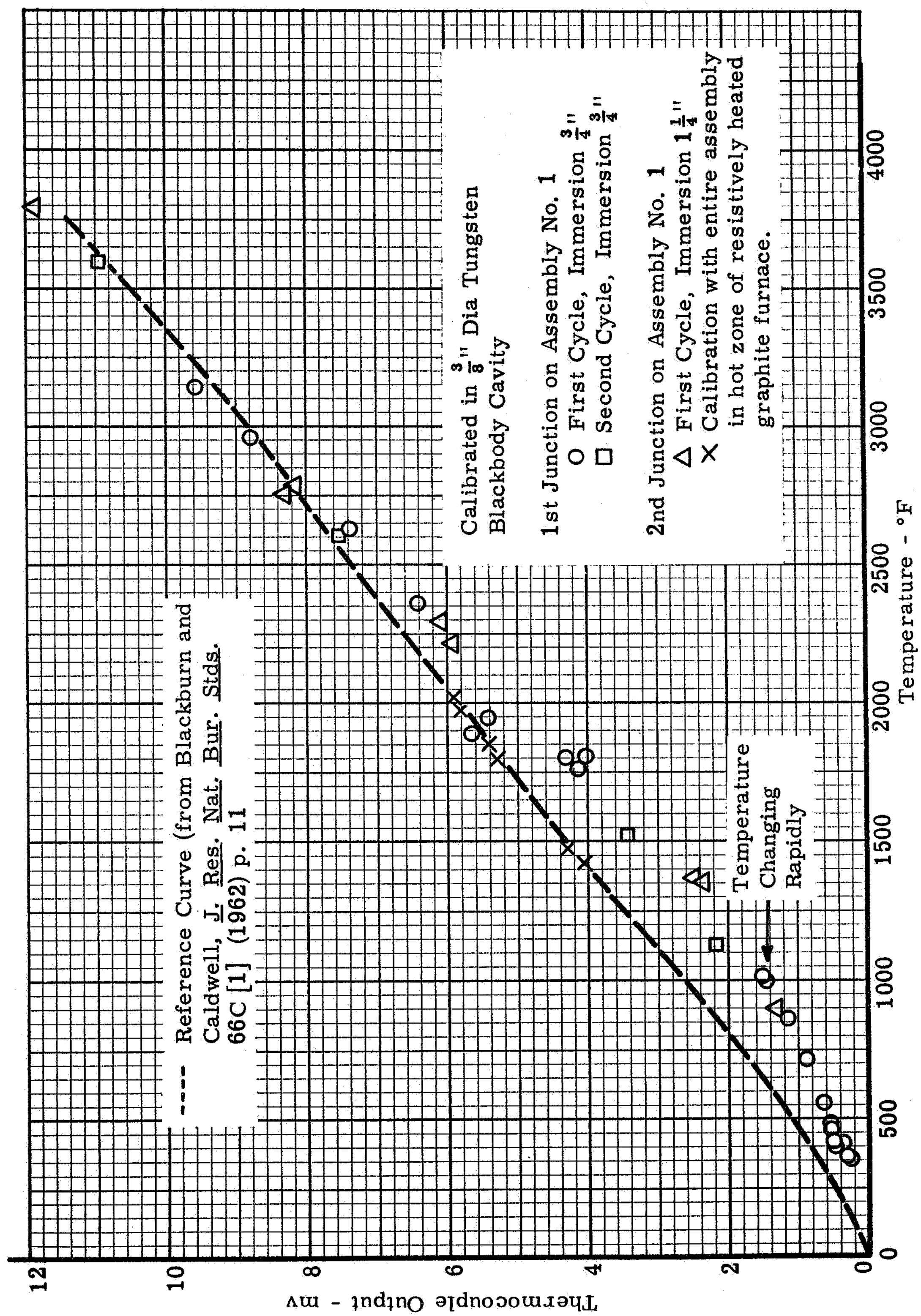


Figure 9. Calibration of Iridium/Iridium-60 Rhodium Thermocouple No. 1 to 3600°F in a $\frac{3}{8}$" Dia Tungsten Cavity and in a $1\frac{3}{4}$" Dia Graphite Heater Tube

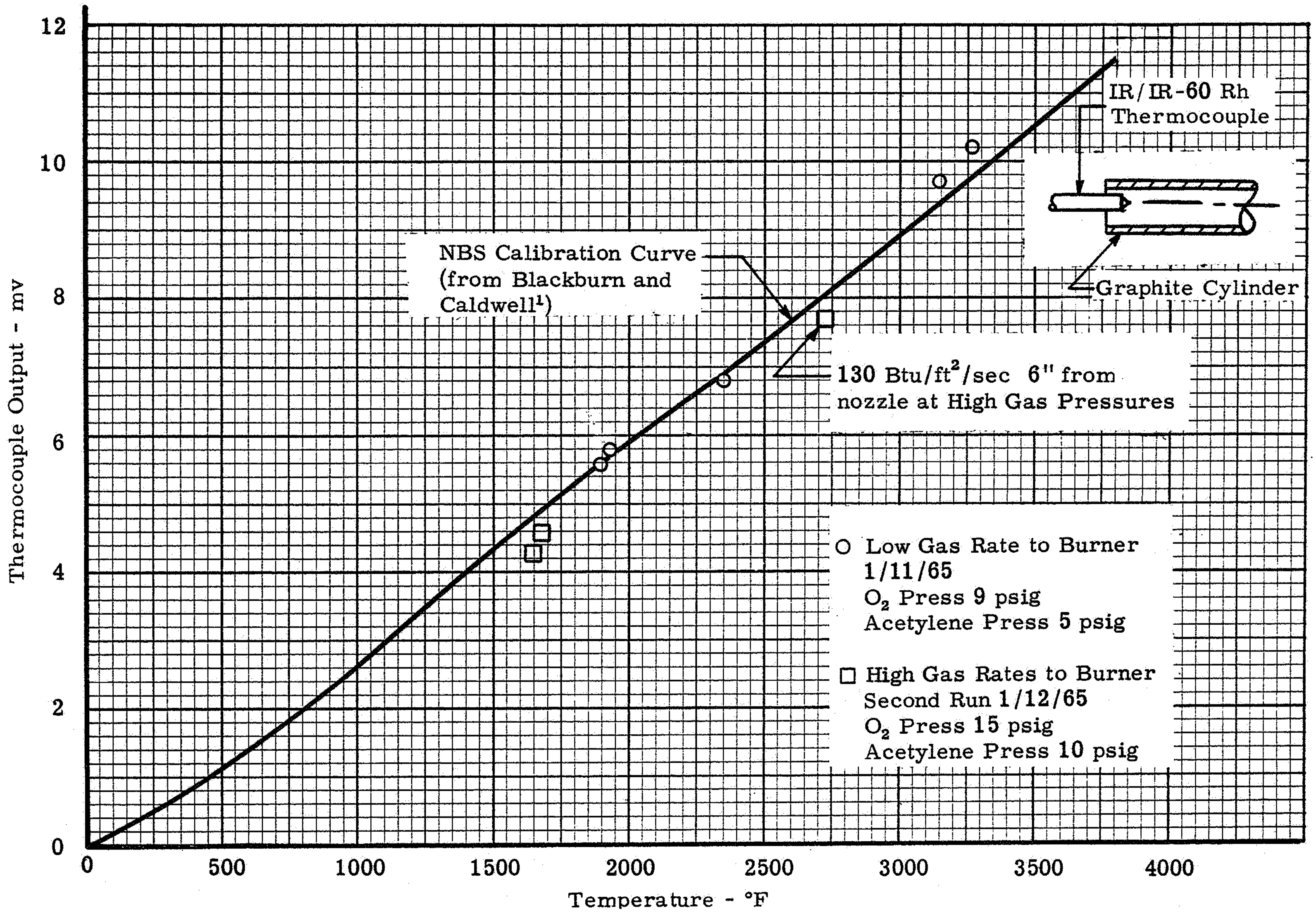


Figure 10. Calibration of Iridium/Iridium-60 Rhodium Thermocouple Assembly No. 1 (New Junction) in the Oxy-Acetylene Flame with Low and High Gas Pressures

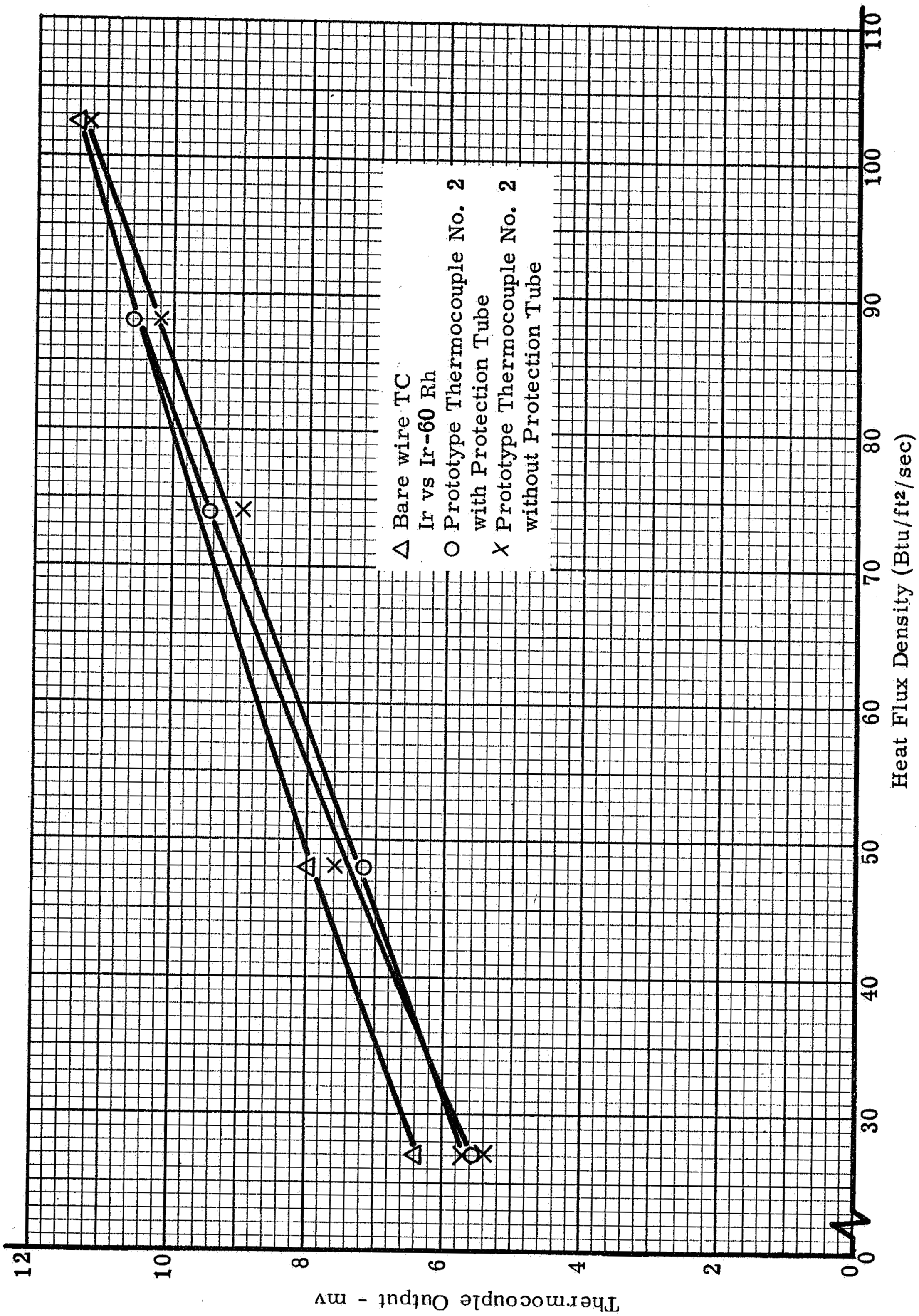


Figure 11. Effect of Stagnation Heat Flux Density on Output of Iridium/Iridium-60 Rhodium Thermocouples

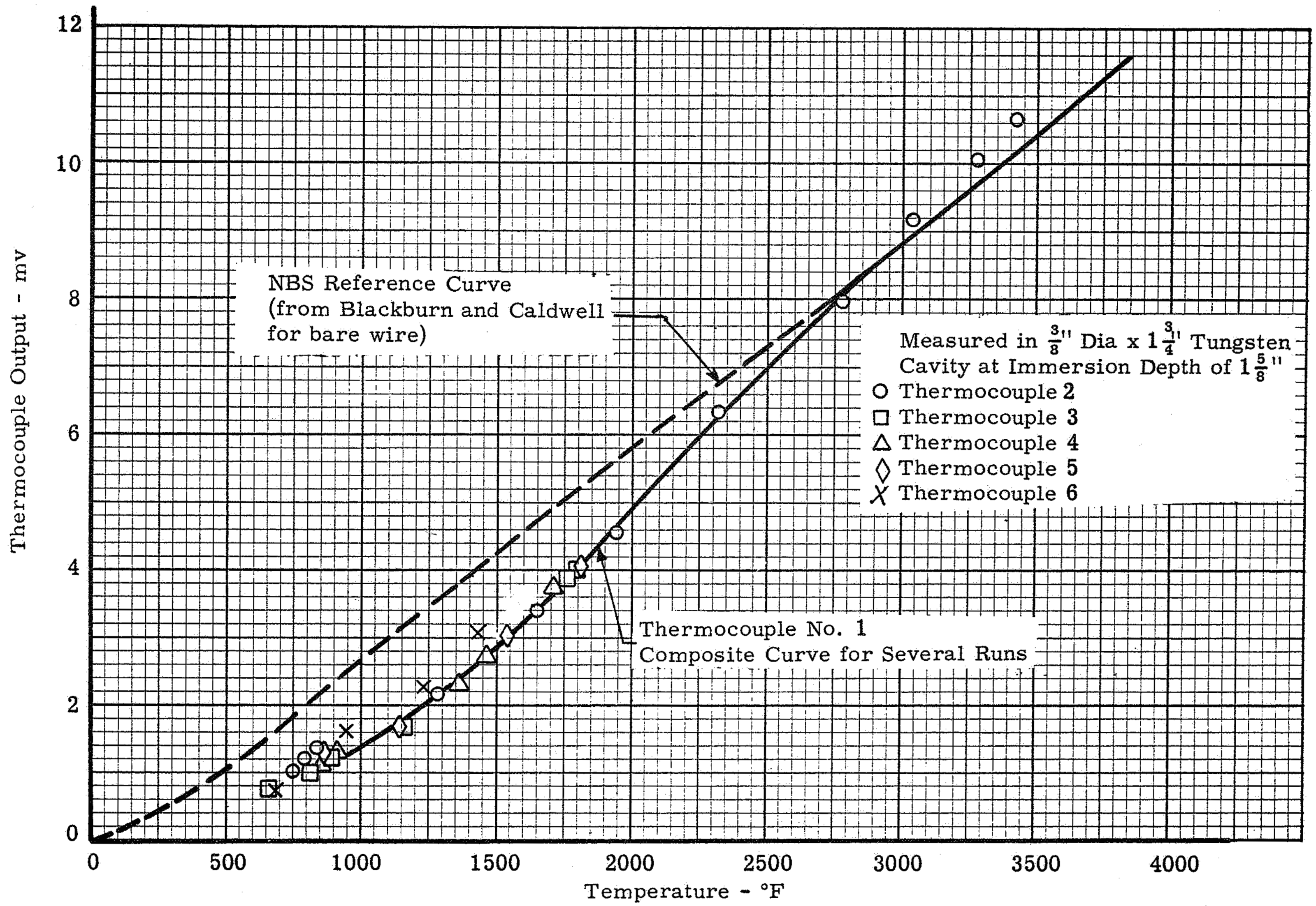


Figure 12. Calibration Data for Thermocouples 1 through 6 (Iridium/Iridium-60 Rhodium)

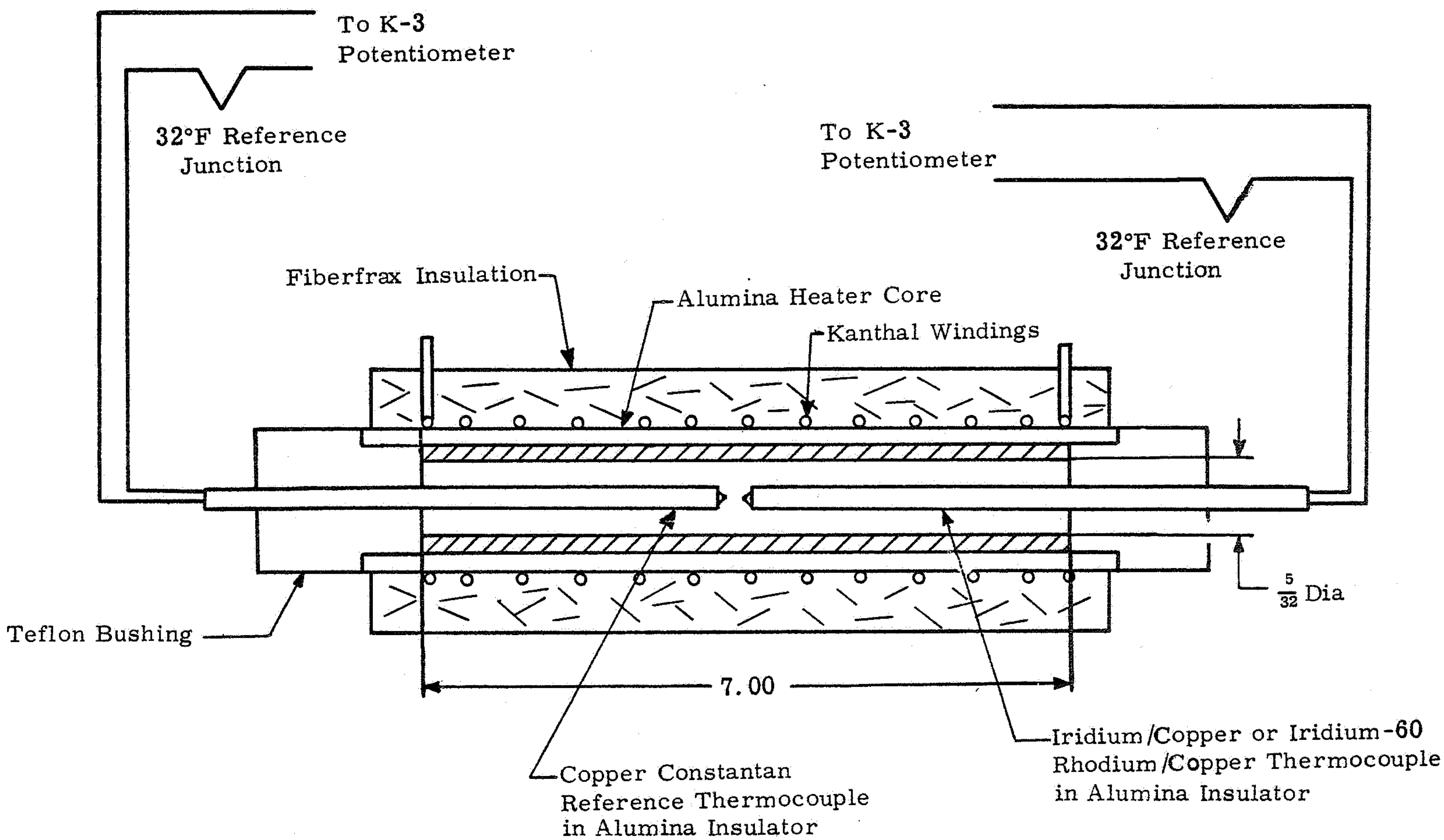


Figure 13. Schematic of Apparatus Used for Calibration of Iridium and Iridium-60 Rhodium vs Copper

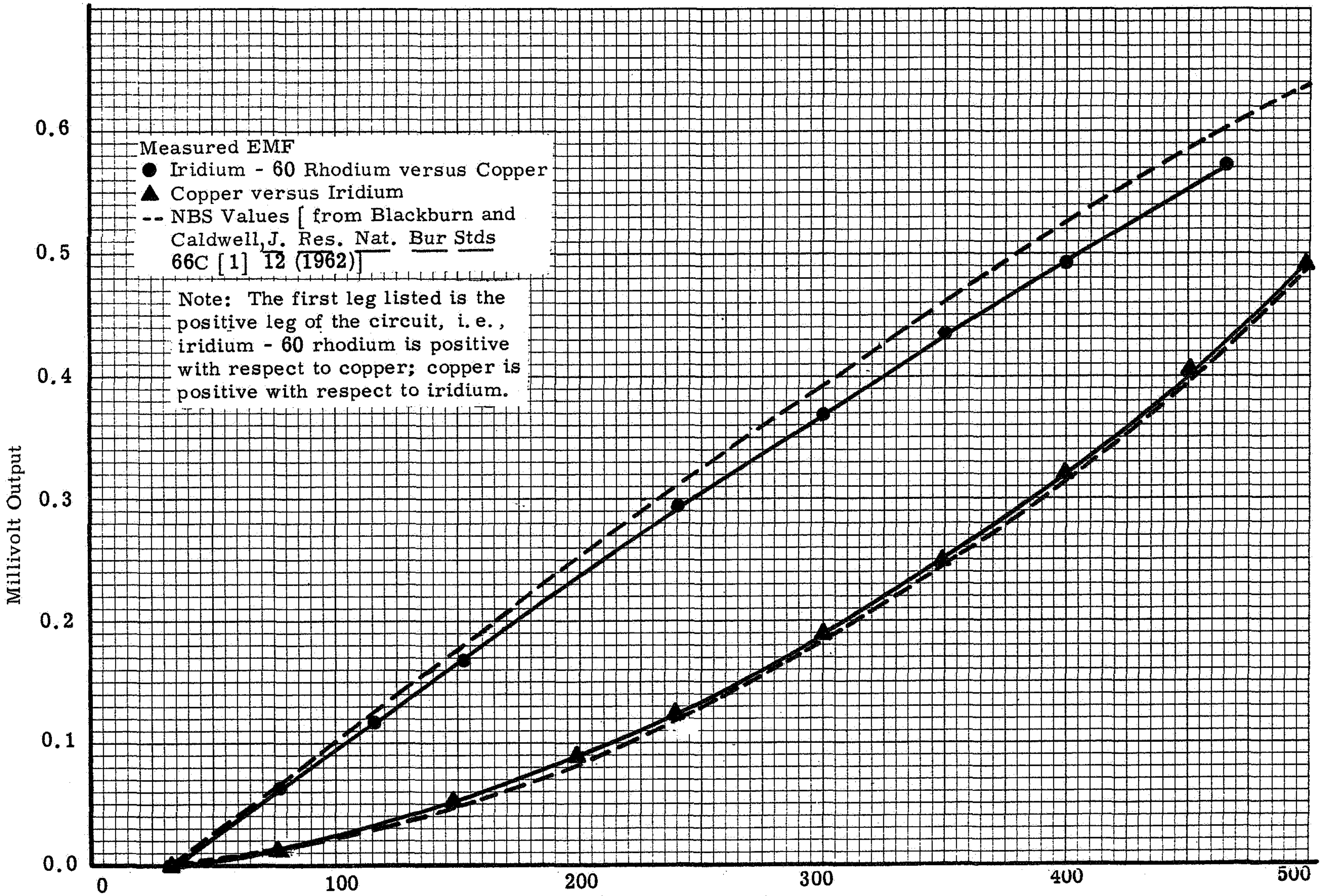
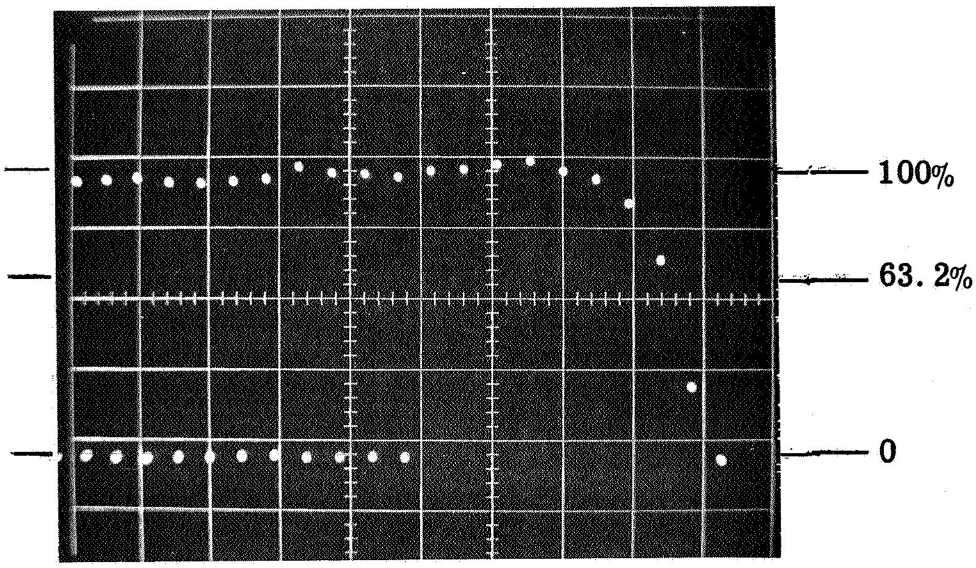
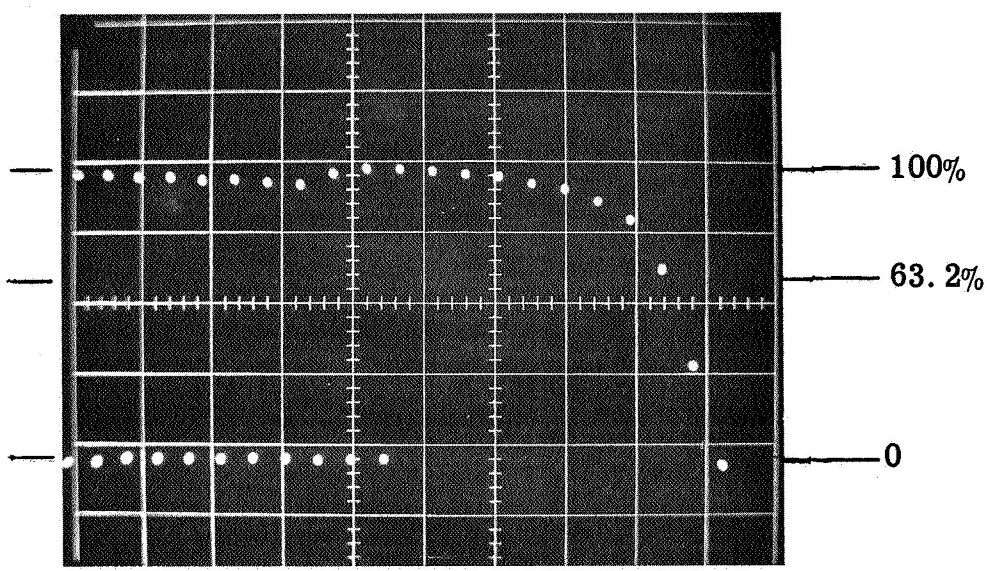


Figure 14. Thermoelectric Output of Copper versus Iridium and Copper versus Iridium - 60 Rhodium

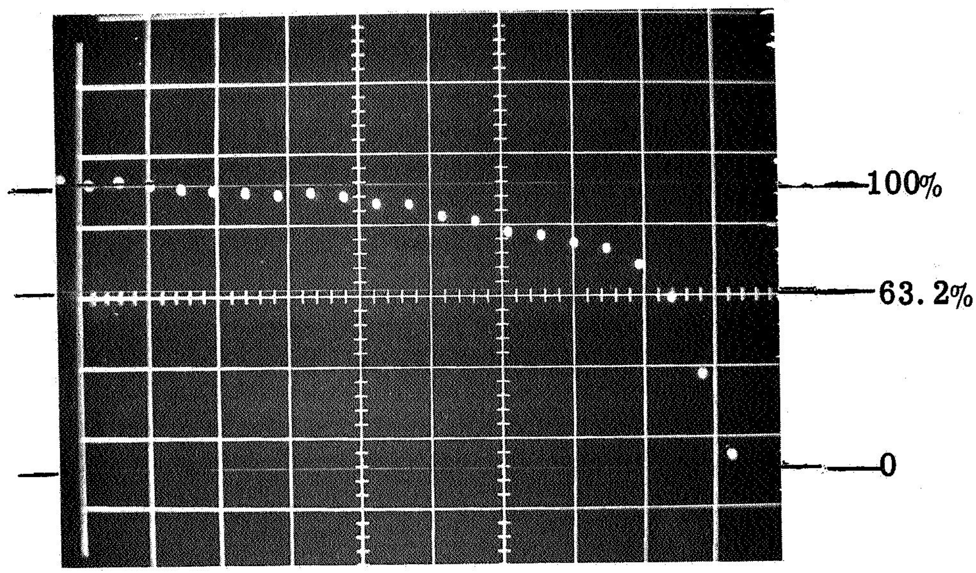


Uninsulated Thermocouple
8" from Burner Nozzle
T = 1.0 sec
HFD = 102 Btu/ft^2/sec

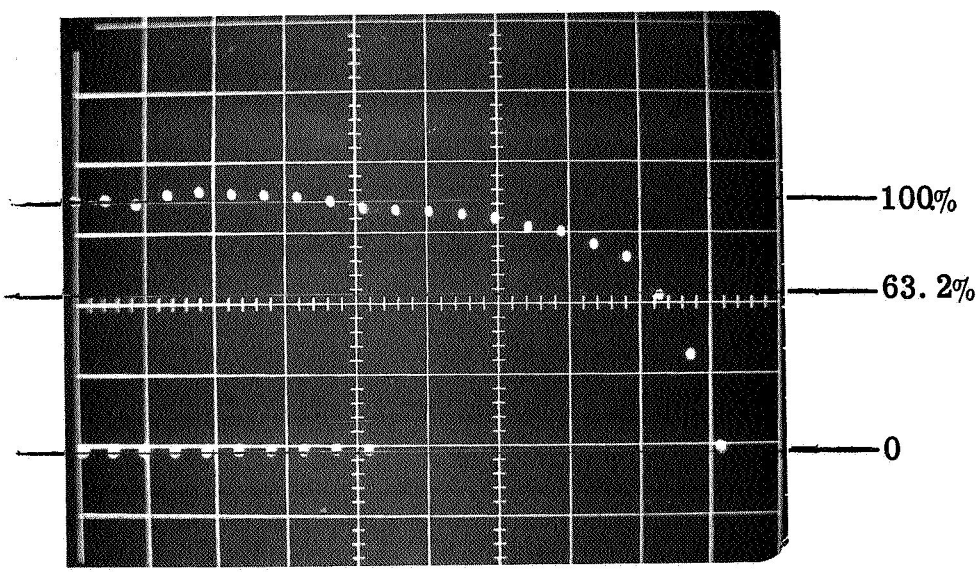


Uninsulated Thermocouple
8" from Burner Nozzle
T = 1.0 sec
HFD = 102 Btu/ft^2/sec

Figure 15. Response Time of Uninsulated (Bare Wire) Iridium/Iridium-60 Rhodium Thermocouple in Oxy-Acetylene Flame



Prototype Thermocouple No. 2 with Protection Tube (105) Installed
8" from Burner Nozzle
T = 1.0 sec
HFD = 102 Btu/ft^2/sec

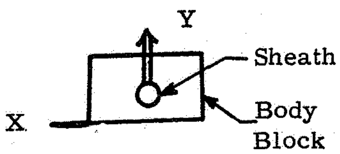
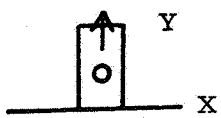
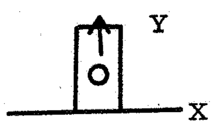
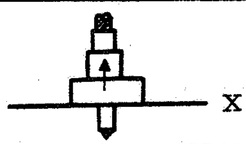
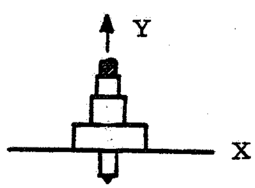


Prototype Thermocouple No. 2 without Protection Tube
8" from Burner Nozzle
T = 1.0 sec
HFD = 102 Btu/ft^2/sec

Figure 16. Response Time of Iridium/Iridium-60 Rhodium Thermocouple No. 2 in Oxy-Acetylene Flame

Table 1

Results of Vibration Tests on Test Model Thermocouples

Test Model	Orientation*	Double Amplitude in.	Frequency cps	Acceleration g's	Time Duration of Test, Seconds	Effects of Tests
Thermocouple No. 1 Test 1		0.125	50	15.9	30	No visible effects
Test 2		0.125	60	22.9	25	No visible effects
Test 3		0.125	55	19.4	20	No visible effects
Test 4		0.125	57	20.6	25	Slight loss of insulation from exposed end of sheath.
Thermocouple No. 2 Test 1		0.125	60	22.9	30	Slight loss of insulation. Weld joining parts 102B and 107 cracked.

* X axis was horizontal axis. Y axis was vertical

Table 2

Reference Tables for Thermoelectric
Output of Iridium vs Iridium-60 Rhodium Thermocouples[1]

Electromotive Force in Absolute Millivolts, Temperature in °F (Int. 1948) Ref. Junction 32°F

°F	0	50
0		0.032
100	0.126	.277
200	.337	.454
300	.576	.706
400	.840	.979
500	1.122	1.268
600	1.418	1.571
700	1.726	1.883
800	2.041	2.201
900	2.361	2.522
1000	2.684	2.846
1100	3.009	3.170
1200	3.332	3.494
1300	3.654	3.814
1400	3.973	4.130
1500	4.287	4.443
1600	4.599	4.753
1700	4.907	5.060
1800	5.211	5.362
1900	5.513	5.664
2000	5.814	5.964
2100	6.114	6.263
2200	6.411	6.560
2300	6.708	6.857
2400	7.005	7.154
2500	7.304	7.455
2600	7.607	7.760
2700	7.914	8.070
2800	8.228	8.388
2900	8.545	8.703
3000	8.862	9.021
3100	9.182	9.344
3200	9.508	9.673
3300	9.839	10.007
3400	10.176	10.348
3500	10.522	10.699
3600	10.879	11.061
3700	11.243	11.426
3800	11.610	

1. From Blackburn and Caldwell, *J. Res. Nat. Bur. Stds.*, 66 C[1] (1962) p. 11.

Table 3

Calibration of Iridium vs Copper and Iridium-60 Rhodium vs Copper

Iridium-60 Rhodium versus Copper

Time	Copper-Constantan Standard mv	°F	Ir-60 Rh vs Cu mv	NBS[1] Ref values for Ir-60 Rh vs Cu mv	% Diff
10:00	1.0100	77.9	.0658	.067	-1.5
10:30	1.8920	116.0	.1180	.125	-5.6
11:00	2.7842	153.0	.1688	.180	-6.1
11:30	5.0601	241.8	.2941	.313	-6.1
	6.6684	300.8	.3680	.393	-6.5
	8.0946	351.1	.4331	.460	-5.9
	9.5378	400.4	.4908	.526	-6.7
12:20	11.5393	466.6	.5708	.603	-5.3

Iridium versus Copper

Time	Copper-Constantan Standard mv	°F	Cu vs Ir mv	NBS[1] Ref values for Cu vs Ir mv	% Diff
1:05	.9774	76.4	.0132	.015	-13.3
	2.6707	148.3	.0505	.048	+ 4.2
	3.9572	199.6	.0892	.083	+ 7.2
	5.0002	239.5	.1227	.118	+ 3.4
2:00	6.6504	300.1	.1880	.185	+ 1.6
	8.0830	350.7	.2497	.248	+ .4
	9.5150	399.7	.3194	.314	+ 1.6
	11.0842	451.8	.4032	.397	+ 1.5
2:45	12.5416	499.0	.4879	.484	+ 0.8

The first leg listed is the positive leg of the circuit, i.e. iridium-60 rhodium is positive with respect to copper; copper is positive with respect to iridium.

1. Blackburn and Caldwell, _J. Res. Nat. Bur. Stds._ 66 C 1 12 (1962)

Table 4

Response Time of Iridium vs Iridium-60 Rhodium

Thermocouples Exposed to an Oxy-Acetylene Flame

Distance from Burner Nozzle in.	Stagnation Heat Flux Density $Btu/ft^2/sec$	Time Constant - sec Prototype Thermocouple 2*		Uninsulated** Thermocouple (Bare Wire)
		Protection Tube On	Protection Tube Off	
8	102	1.0	1.0	1.0
8	102	1.0		1.0
11	61			1.0
14	27	2.0		1.7
14	27			2.0

* Bead diameter of prototype thermocouple No. 2 was 0.047 in.

** Bead diameter of uninsulated thermocouple (bare wire) was 0.058 in.